

Four Years of ACIS: Monitoring Detector Performance

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1 Introduction

Over the lifetime of Chandra, the performance of the Advanced CCD Imaging Spectrometer (ACIS) continues to evolve. The instrument team has an ongoing program of monitoring and analysis to track long term trends and detect any instrument anomalies. I present the four year history of selected ACIS characteristics to the present time and discuss expectations for the future. I will also describe, in general terms, how this evolution affects science data calibration.

2 Data

All the results shown here are based on data taken of the ACIS External Calibration Source. Since the discovery of the initial radiation damage, a continuing series of observations have been undertaken just before and just after the instruments are safed for perigee passage to monitor the performance of the ACIS CCDs. ACIS is placed in the HRC-S position exposing the CCDs to the External Calibration Source which produces many spectral lines including Mn-K α (5.9 keV), Ti-K α (4.5 keV), and Al-K (1.5 keV). The data are taken in the standard Timed Exposure mode with a 3.2 second frame time. Typical exposure times range from 5.5 to 8 ksecs.

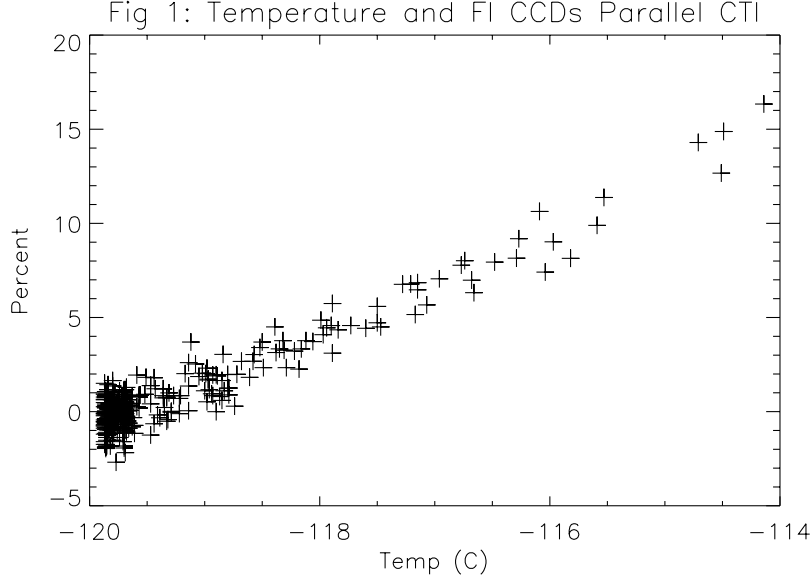
3 Charge Transfer Inefficiency

A symptom of damage in CCDs is an increase in the number of charge traps. When charge is transferred across the CCD to be read out, some portion can be captured by the traps and re-emitted later. If the original charge packet has been transferred away before the traps re-emit, the captured charge is “lost” to the charge packet. The pulseheight of each spectral line drops with increasing transfer distance. Charge Transfer Inefficiency or CTI is defined as the fractional charge loss per pixel at a given energy and is calculated from a linear fit to the pulseheight versus row number; $CTI = (\text{slope}/\text{intercept})$. Damage can exist in the imaging or framestore array, causing parallel CTI in the column direction, or in the serial register, causing serial CTI along rows. The ACIS CCDs come in two flavors, front- and back-illuminated, which have different manifestations of CTI.

3.1 Parallel CTI

3.1.1 Front-illuminated CCDs

The eight front-illuminated CCDs had essentially no CTI before launch, but are strongly sensitive to radiation damage from low energy protons (~ 100 keV) which create traps in the buried transfer channel in the imaging array. The initial radiation damage from low-energy protons in the Earth's particle belts is now prevented by moving the ACIS detector away from the aimpoint of the observatory, however continuing exposure to both low and high energy particles will slowly degrade the CTI.



The characteristics of the traps in the FI CCDs are highly sensitive to the ambient particle background and the focal plane temperature. Monitoring the actual level of radiation damage requires removing both these effects. **Figure 1** shows the effect of small changes in focal plane temperature on the measured CTI of the FI CCDs in the ACIS-I array.

Figure 2 shows the mean CTI of the I-array at 5.9 keV since January 2000 after removing the effect of changing background and temperature. The CTI increase is of order 3×10^{-6} per year or about 2.5%.

3.1.2 Back-illuminated CCDs

The two back-illuminated CCDs (ACIS-S1,S3) suffered damage during the manufacturing process and exhibit CTI in both the parallel and serial transfers, but are less sensitive to the low energy particles which damage the FI CCDs because they cannot reach the buried transfer channel. **Figure 3** shows the parallel CTI of S3 at 5.9 keV since January 2000. The CTI increase is of order 1×10^{-6} per year or about 7%.

3.2 Serial CTI

Both types of device are sensitive to high energy particles (> 1 MeV) which can damage the imaging, framestore and serial arrays. **Figures 4 and 5** show the serial CTI for the I-array and for S3. Only the bottom 150 rows were used to calculate serial CTI to prevent cross-talk between

Fig 2: Parallel CTI for FI CCDs: ACIS I-array

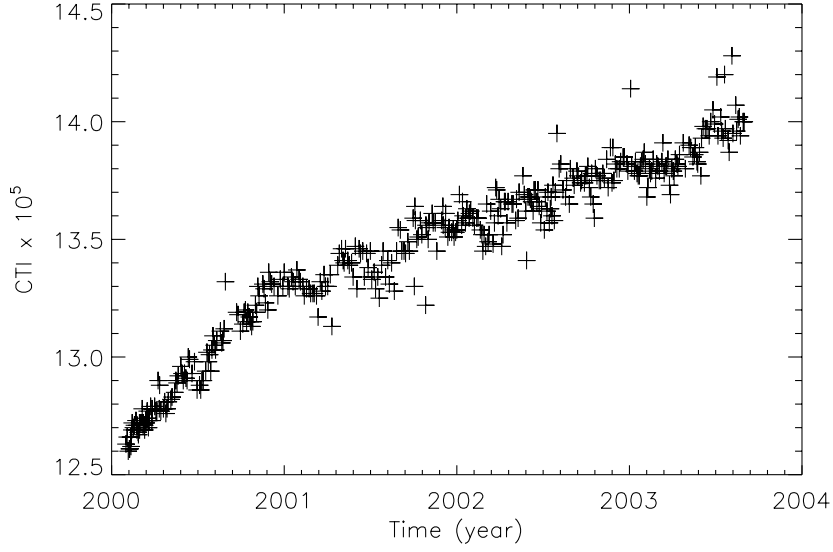
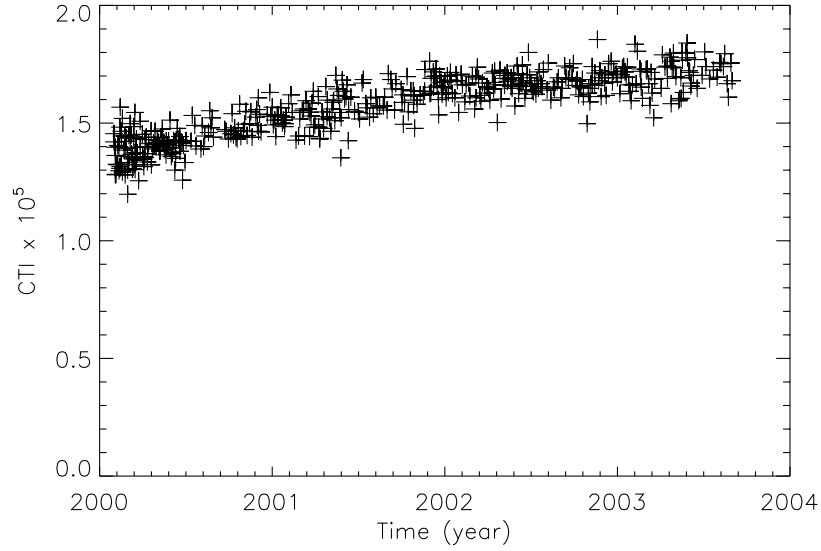


Fig 3: Parallel CTI for BI CCD: ACIS-S3

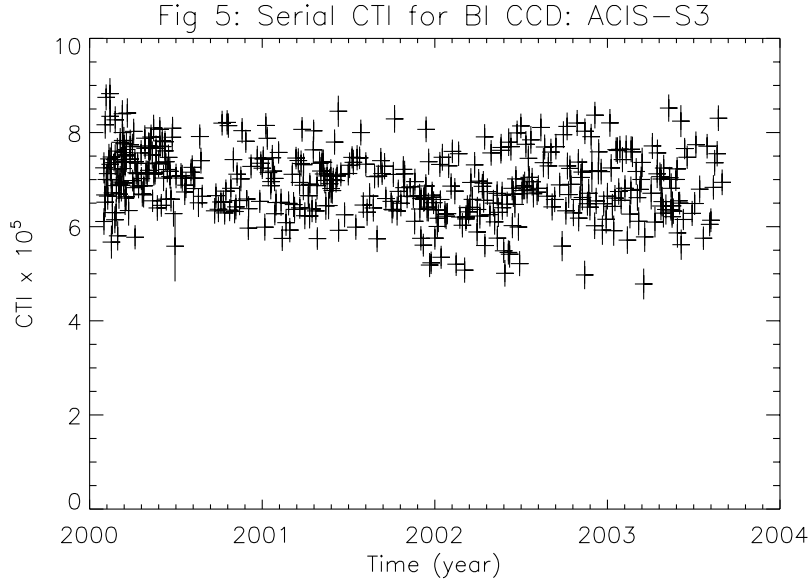
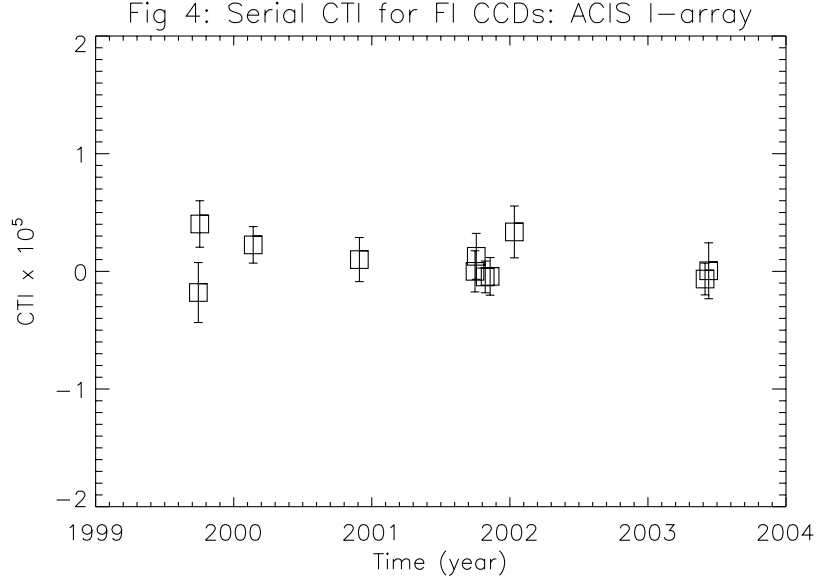


serial and parallel CTI. To increase the signal to noise for each point, only I-array measurements with the longest exposure times (15 - 50 ksec) were included. In both cases, strong limits can be put on any increase of $\ll 10^{-6}$ per year.

4 Detector Gain

As the ACIS electronics age, it is expected that the detector gain will slowly change with time. The gain is measured by a linear fit to the energy/pulseheight relation for the three strongest spectral lines in the calibration source, i.e.

$$\text{Pulseheight (ADU)} = \text{Slope (ADU/eV)} \times \text{Energy (eV)} + \text{Offset (ADU)}.$$



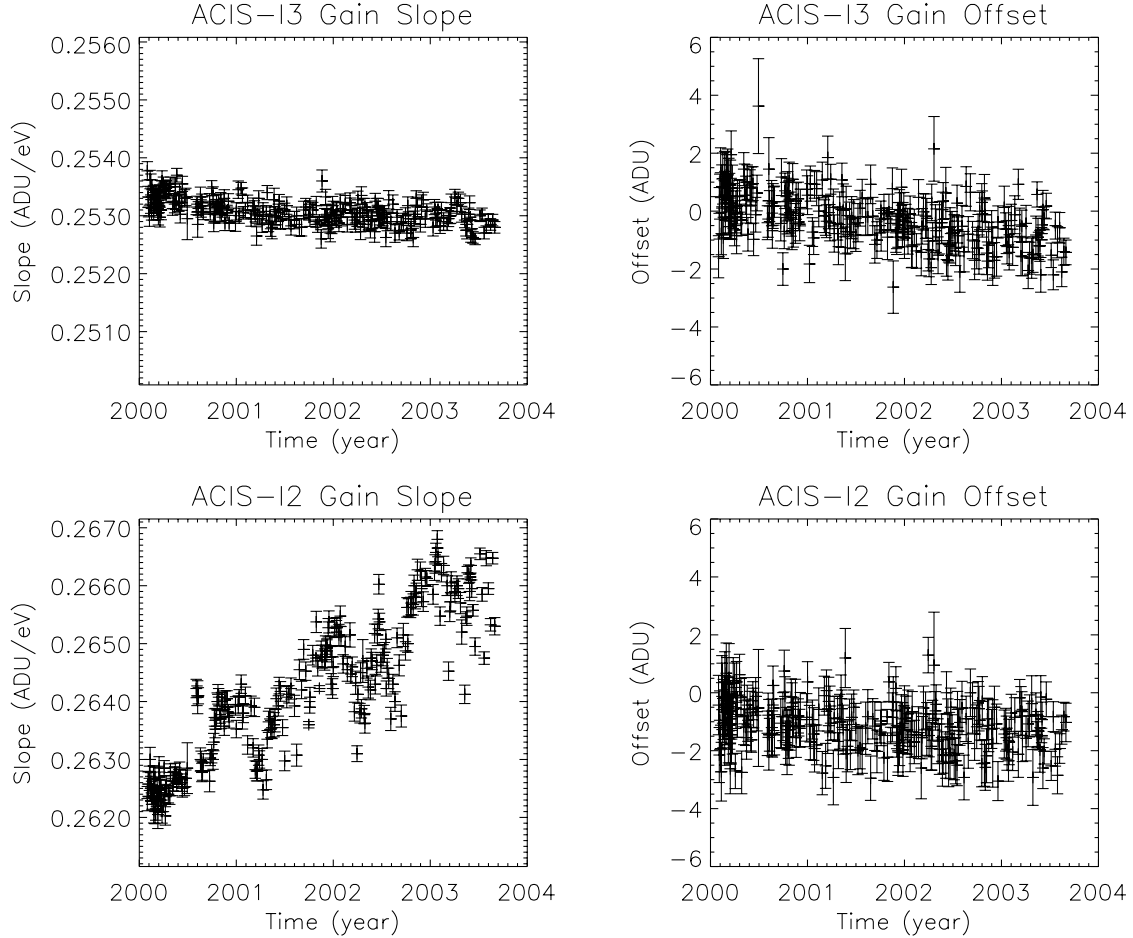
Since CTI will also change the measured gain, only data from the bottom 20 rows of the CCDs is used.

Figure 6 shows the slope and offset of the detector gain for a typical case, ACIS-I3, and an anomalous case, ACIS-I2. For most CCDs, the slow decay in gain would yield a decrease in pulseheight of 0.2% at 5.9 keV since January 2000, while I2 would show an increase in pulseheight of 1.3% at 5.9 keV. We do not currently have a satisfactory explanation for this behavior, but it appears to be limited to I2.

Charge Transfer Inefficiency Summary

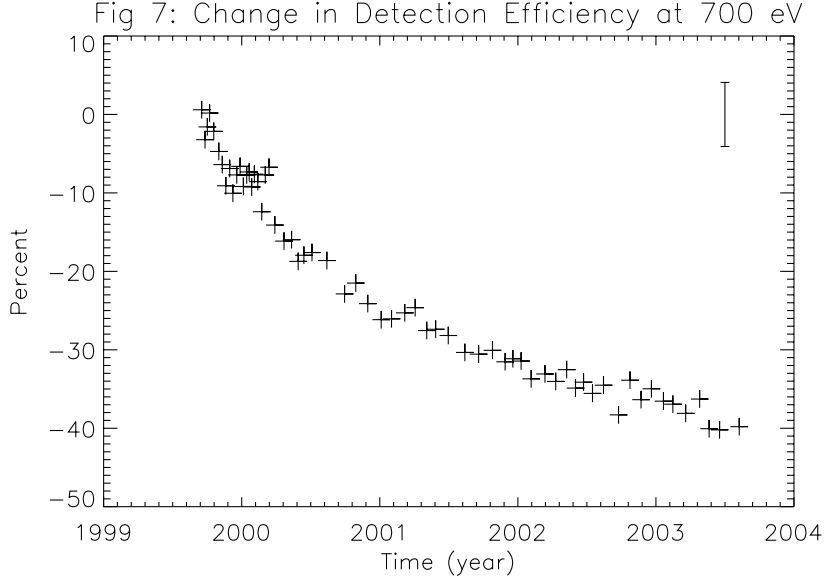
	Pre Launch	Jan 2000	Rate of Change
FI Parallel	$< 3 \times 10^{-6}$	$1 - 2 \times 10^{-4}$	$3.5 \times 10^{-6} / \text{year}$
FI Serial	$< 2 \times 10^{-6}$	$< 2 \times 10^{-6}$	$< 6 \times 10^{-7} / \text{year}$
BI Parallel	1.4×10^{-5}	1.4×10^{-5}	$1.0 \times 10^{-6} / \text{year}$
BI Serial	7.6×10^{-5}	7.3×10^{-5}	$< 1 \times 10^{-7} / \text{year}$

Figure 6



5 Detector Efficiency

The ACIS team is involved in the ongoing investigation into the degradation of the low energy QE due to a contaminant. The chemical composition of the contamination is being studied with LETG spectra of astrophysical objects (Marshall et al. 2003, astro-ph/0308322), however the more frequent observations of the ACIS calibration source allow for better study of the deposition rate. The ACIS calibration source, in addition to the strong high energy lines, also has a weaker low energy complex at 670 eV from a combination of Mn and Fe L-lines. **Figure 7** shows the change



in detection efficiency at this complex since launch. Calibration source studies are also yielding information on the spatial distribution of the contaminant which will be incorporated into future correction tools.

6 Effect on Science Data Calibration

Pulseheight: The evolution of both the detector gain and CTI will change the energy to pulse-height conversion which is tabulated in the CALDB gain file. **Figure 8** shows the change in pulseheight as a function of time for three cases: a typical BI CCD S3, a typical FI CCD I3, and the anomalous CCD I2. The pulseheight change for the normal CCDs is always larger far from the readout where CTI effects dominate, however the reverse is true for I2 where the anomalous gain dominates. The evolving pulseheight has been tabulated and can be corrected in science data by using the `corr_tgain` tool available on the CXC contributed software page. This correction will also be incorporated into a future version of `acis_process_events`.

Line Width: A higher-order effect of increasing CTI is the broadening of line widths. **Figure 9** shows the change in linewidth as a function of time for two cases: S3 and I3. The width change for the BI CCD S3 is minimal, with an increase of $\sim 5\%$ or 1 ADU since January 2000. The change for the FI CCDs is larger, of order 5-8 ADU. Since this increase is due to charge smearing of split events, it is much smaller at lower energies. For many users this small change will not affect their science analysis. The Penn State CTI Corrector, available on the CXC contributed software page, incorporates a simplified linearly changing CTI which will help remove both the gain and width changes. Users should be aware that the PSU CTI corrector is incompatible with `corr_tgain`.

Efficiency: The loss of low energy efficiency from contaminant deposition will effect broad-band flux measurements, and normalizations and absorber column density in spectral fitting. The CXC has developed an analysis thread which describes how the user can adjust their effective area files to correct for the excess absorption. A bakeout of the detector is currently under discussion and, if executed, should reduce the contaminant thickness.

Fig 8: Pulseheight Change at 5.9 keV

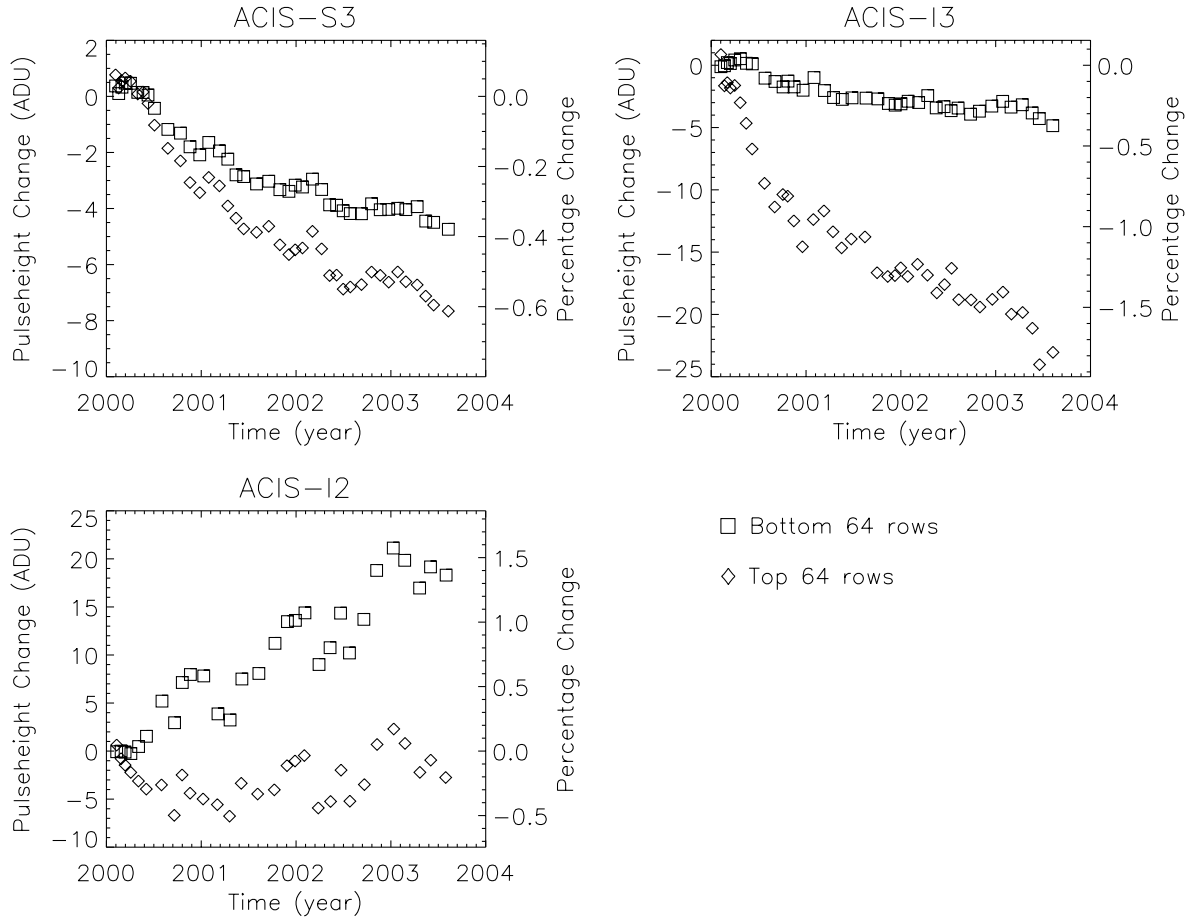


Fig 9: FWHM Change at 5.9 keV

